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ScienceDirect
Procedia Engineering 65 (2013) 358 – 363
Procedia Engineering
www.elsevier.com/locate/procedia

Concrete and Concrete Structures 2013 Conference

Stress and Strain Behaviour of Composite Elements at Elevated Temperatures

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Abstract

The article deals with the problem of using new types of reinforcement for concrete structures, in particular with the non-metallic glass fiber reinforced polymers - GFRP. The article briefly describes the properties of the reinforcement and highlights the need for further research. Provided a planning process for experiments to determine the state of stress into GFRP reinforced concrete elements at elevated temperatures. The experiment is based on investigations already carried out with conventional steel reinforced elements.

Selection and peer-review under responsibility of University of Zilina, Faculty of Civil Engineering, Department of Structures and Bridges

Keywords: GFRP reinforcement; steel reinforcement; temperature; stress; relative length strain; shrinkage;

1. Introduction

The topic of this article is the issue of stress and strain of composite elements at elevated temperatures. Mentioned composicity occurs here in two dimensions, namely:

- At the level of the composite test specimen;
- At the level of reinforcement as a composite product FRP.

In contrast to concrete elements reinforced with steel bars for elements reinforced with FRP due to the composicity and possible variations of the properties of FRP, a great potential for further research activity exists. For this reason,

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Selection and peer-review under responsibility of University of Zilina, Faculty of Civil Engineering, Department of Structures and Bridges
doi:10.1016/j.proeng.2013.09.055

the methodology and results of experiments performed on specimens reinforced with conventional steel and composite FRP reinforcement are shown in the article.

2. Fiber reinforced polymers (FRP)

In general, fiber reinforced polymers (FRP) as internal reinforcement has a high chemical stability and corrosion resistance. For this reason, it is increasingly used in cases very corrosive conditions (e.g. bridge decks, car parks). FRP reinforcement is non-magnetic, except carbon fiber reinforced polymers. Other positive features are negligible specific heat conductivity and low weight.

FRP are created by embedment of reinforcing fibers in a resin matrix. Fibers represent about 40 - 70% of composite. The remaining percentage consists of the resin matrix and the filler. The resin also protects fibers from damage due to mechanical, chemical and physical load.

2.1. Reinforcing fibers

Glass, carbon, aramid, polyethylene, polypropylene, polyester and nylon can be used as reinforcement. The most commonly used one are glass, carbon and aramid. These materials are characterized by linear - elastic material behavior up to rupture. Therefore, they fail brittle, in contrast to steel, which exhibits a pronounced ductile behaviour. The modulus of elasticity decreases from carbon through aramid to the glass as shown in Table1.

Table 1: Properties of fibers

Fiber	Modulus of elasticity	Tensile strength	Ultimate strain	Volume weight	Viscosity ν	Thermal expansion	Temperature stability up to
	[GPa]	[GPa]	[‰]	[kg/m^3]	[-]	[10^{-6} K^{-1}]	[°C]
Aramid	80 - 186	3.4 – 3.8	20 - 40	1450	0.35	-2 / 59	100
E-glass	73 - 75	3.4 – 3.6	46 - 48	2500 - 2700	0.20	5.0 / 5,0	200
AR- glass	73 - 76	1.8 – 3.5	25 - 43	2700	0.20	6.5 / 6,5	200
Carbon	250 - 650	3.0 – 5.8	4 - 20	1600 - 2000	0.20	-1.5 ~ -0.1 / 7 ~ 15	400

2.2. Matrix

Thermoplastics and thermosets particularly (reactive resin) are used as matrix. The most widespread resins in FRP reinforcement are unsaturated polyester resins, vinylester resins and epoxy resins. Because of their very low viscosity (ν) they can well wet fiber bundle in production. They are generally stable at elevated temperatures (see Table 2). As the resin matrix has significantly smaller modulus of elasticity than fibers. Basically the reinforcing fibers transmit stress.

Table 2: Properties of resins

Resin	Modulus of elasticity	Tensile strength	Limit strain	Volume weight	Viscosity ν	Thermal expansion	Glass transition temperature
	[GPa]	[GPa]	[‰]	[kg/m^3]	[-]	[10^{-6} K^{-1}]	[°C]
Polyester	2.1 – 4.4	34.5 – 103.5	10 - 42	□ 1300	0.2 – 0.33	60 - 150	93 - 150
Vinylester	3.0 – 3.8	73 - 95	10 - 61	□1100	0.2 – 0.33	45 - 90	50 - 260
Epoxid	2.6 – 4.1	3.8 - 176	18 - 130	1200 - 1300	0.33 – 0.40	20	70 - 300

2.3. Filler

Various fillers are used as additives to the liquid resins as to regulate some characteristics of the fresh and hardend resin, e.g. calcium carbonate, aluminum trihydrate, mica, quartz, feldspar, talc, kaolin, glass particles, silica fume and others.

3. Experiment

3.1. Motivation

The specific mentioned properties were motivation for the experimental of embedded GFRP reinforcement at elevated temperatures in order to determine the impact of the new type of reinforcement on internal stresses in the elements.

3.2. Methodology for testing

Measurements were based on similar tests previously performed [2-3] at the Faculty of Civil Engineering, TUKE. The methodology is directly related to performed work reported in [1-3] [5-6]. In cited projects, relative length strain from shrinkage of beams reinforced by conventional steel reinforcement (μ= 1.13%; 2.01% a 2.80%) at normal and elevated temperatures (20 °C , 40 °C , 80 °C , 100°C) was measured. The relative length strain was measured on specimens in the first 28 days at room temperature. Then the temperature was increased in steps of 20°C. The specimens were exposed to constant temperature for 24 hours every time. At the end of each level the relative length strain was measured.

For the experiments beams reinforced with conventional steel and as well as with FRP reinforcement were selected. Whit these elements measurements were conducted as already described above. To illustrate the expected results we are presenting here the results (in the form of graphs) of measurements from [1] and the partial results of our own measurements.

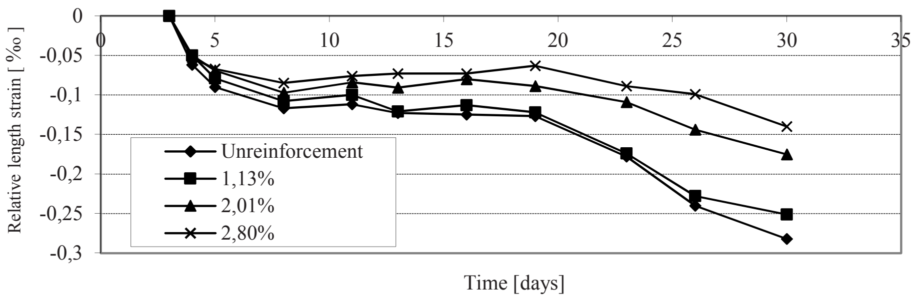

Fig. 1. Relative length strain, beams with conventional steel reinforcement, temperature about 20 ° C [3]

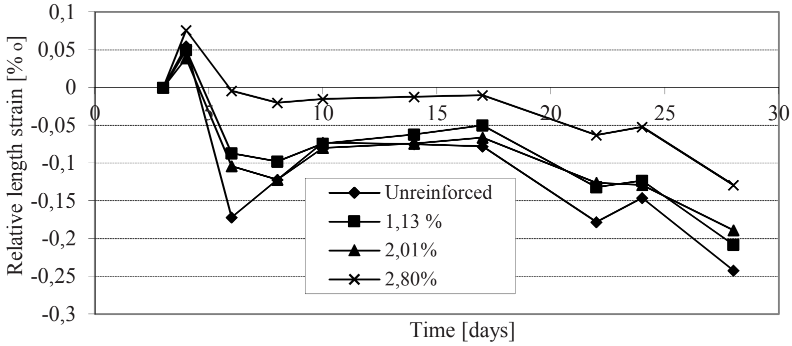

Fig. 2. Relative length strain, beams with conventional steel reinforcement, temperature about 20 ° C [2]

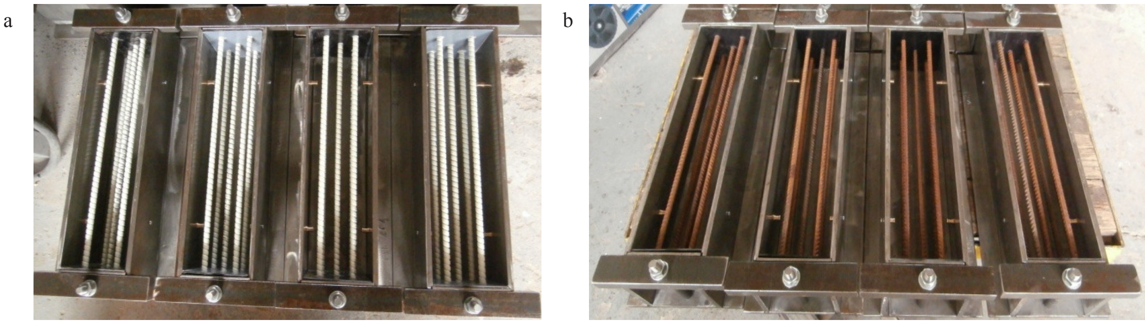

Fig. 3. Prepared forms with reinforcement – (a) FRP and (b) steel

After measurement of test specimens at ambient temperature the measurements at elevated temperatures were performed, starting 28 days after pouring of the concrete. For illustration the results gathered with beams reinforced with steel reinforcement are presented in [1] Fig. 5. and Fig. 6. The graphs show that the degree of reinforcement has significant influence on internal stress in cross section and capacity of cross section, when it is exposed to heat.

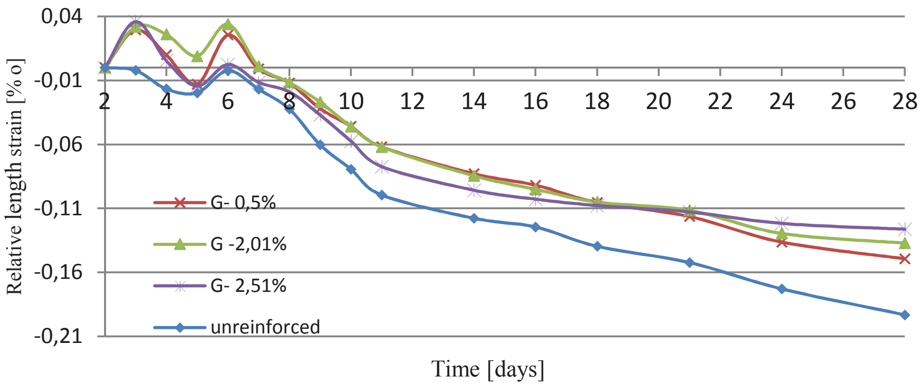

Fig. 4. Relative length strain, temperature about 20 ° C – GFRP

The beams reinforced by GFRP reinforcement will be loaded and measured in this manner too.

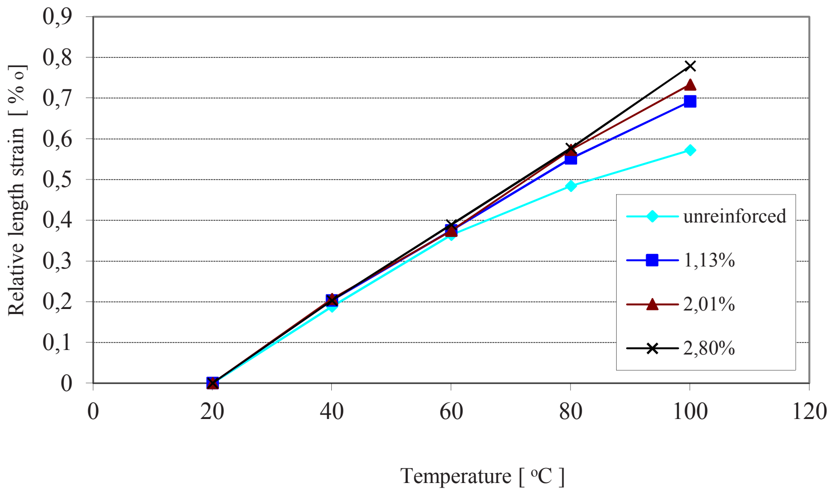

Fig. 5. Relative length strain of samples at elevated temperature [3]

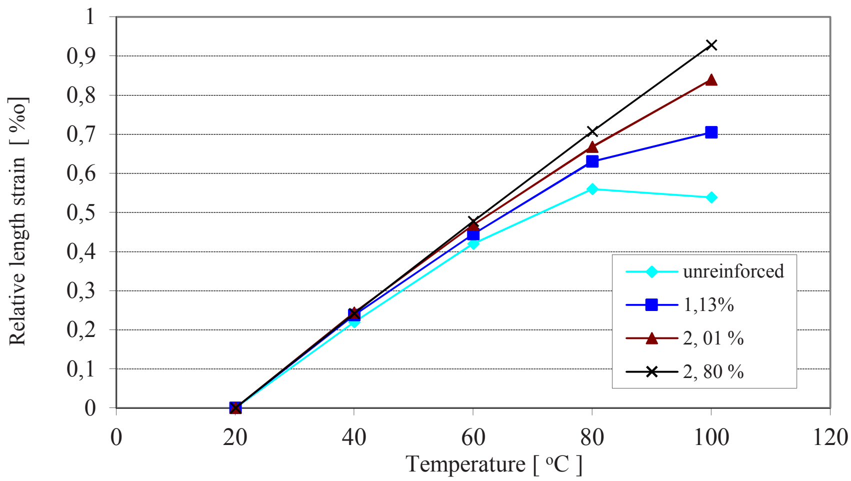

Fig. 6. Relative length strain of samples at elevated temperature [2]

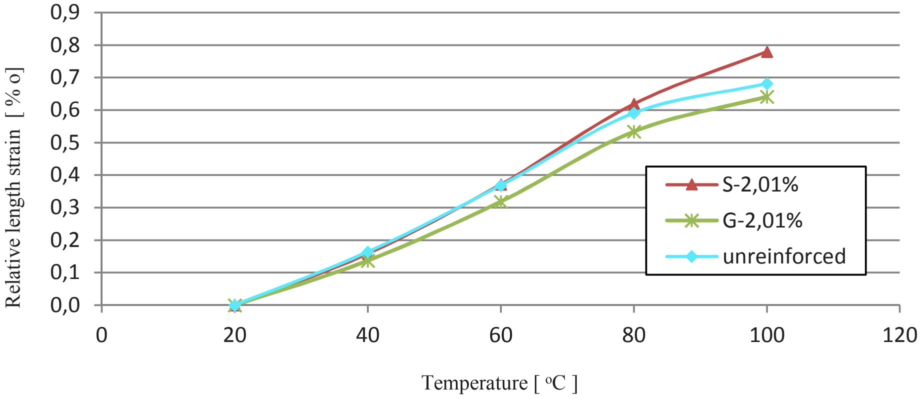

Fig. 7. Relative length strain of samples at elevated temperature (S- steel, G- GFRP reinforcement)

4. Conclusion

Presented results for beams reinforced with conventional steel, as well as preliminary test results for beams reinforced with FRP reinforcement refer to need for solve this problem, because internal stresses arising from different shrinkage, creep and thermal expansion modulus cannot be neglected in general. It is necessary to determine the minimum temperature limits, and limits for degree of reinforcement, to which it is still possible to neglect it with sufficient safety margin.

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